

BEYOND EINSTEIN: From the Big Bang to Black Holes

Constellation

The Constellation X-Ray Mission

►► Future X-ray Observatories

Presented by

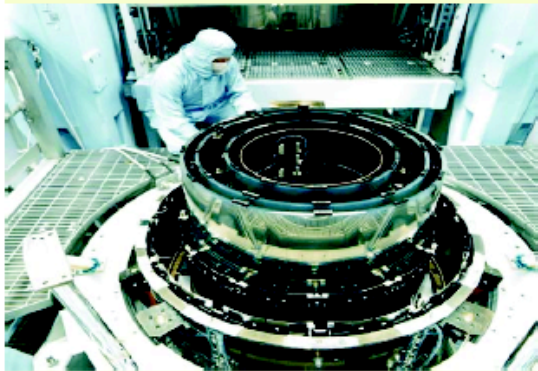
**Ann
Hornschemeier**

**Deputy Project Scientist,
Constellation-X (GSFC)**

*Making the Most of the Great Observatories
May 22-24, Pasadena, CA*

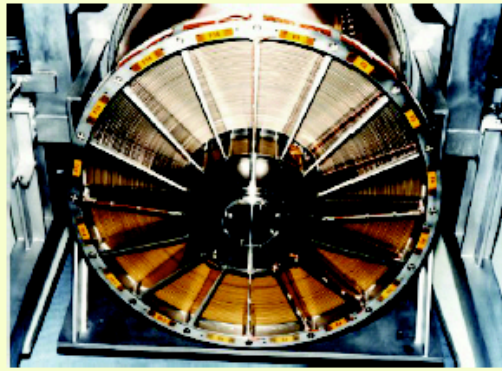


A Quick Primer on X-ray Optics: *They are extremely heavy.*



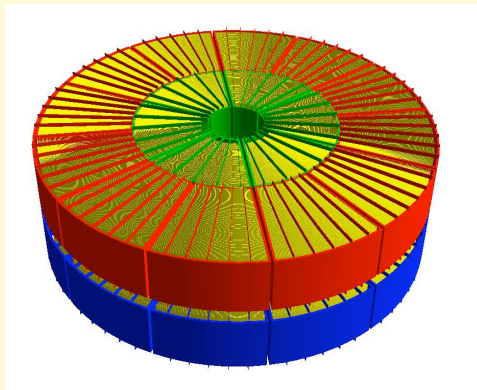
CHANDRA
0.5"

18500 kg/m²
 A_{eff} @ 1 keV



XMM-NEWTON
14"

2300 kg/m²
 A_{eff} @ 1 keV



CON-X
5-15"

250 kg/m²
 A_{eff} @ 1 keV

credit: Marcos Bavdaz, ESA-XEUS team

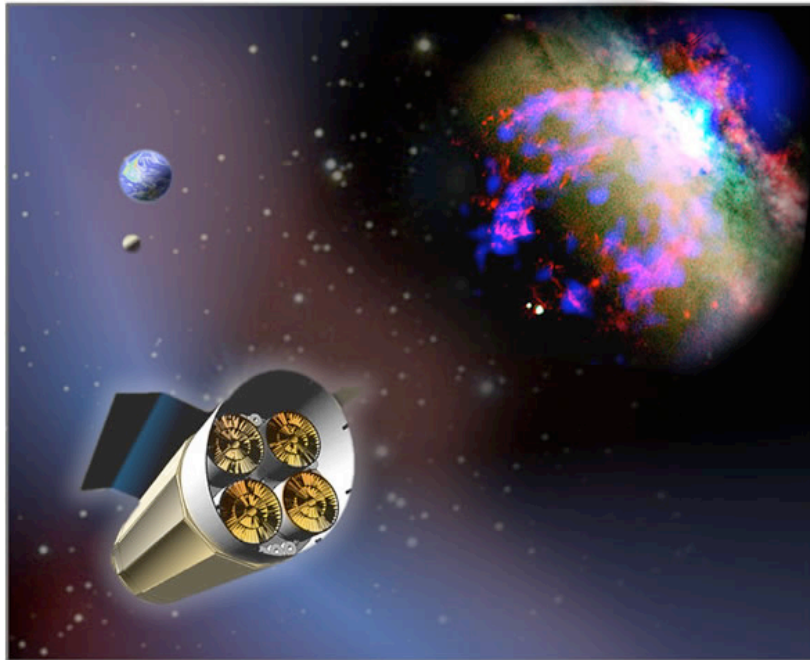
Heroic Grating observations from Chandra and XMM-Newton are providing the first glimpse of the power of X-ray Spectroscopy



Figure 1 consists of four panels showing the rest-frame optical spectra of the quasar J0000-0334. The top panel displays the full spectrum from 1.5 to 4.5 μm , with the x-axis labeled 'Rest Energy [eV]' at the top. The y-axis is 'Flux [$\times 10^{-13} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$]'. The second panel zooms in on the 4.5 to 7.5 μm range. The third panel zooms in on the 7.5 to 10.5 μm range. The bottom panel zooms in on the 10.5 to 14 μm range, with the x-axis labeled 'Rest Wavelength [\AA]'. Each panel shows the observed flux (black line) and various absorption features identified with different elements (Fe, Ca, Ar, S, Al, Mg, Si, Ne) using color-coded vertical bars and labels.

<http://constellation.gsfc.nasa.gov>

The Constellation-X Mission



NGC 3079

Science Goals:

- **Black Holes**
 - Probing strong gravity
 - Evolution & effects on galaxy formation
- **Dark Matter and Dark Energy**
 - Cosmology using clusters of galaxies
- **Cycles of Matter and Energy**
 - Cosmic feedback, extreme states of matter, stellar coronae, supernovae, planets, etc..

A suite of X-ray telescopes for high resolution spectroscopy:

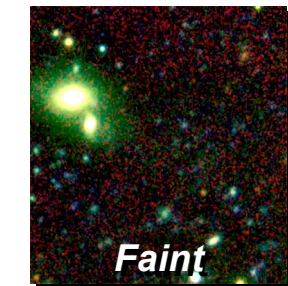
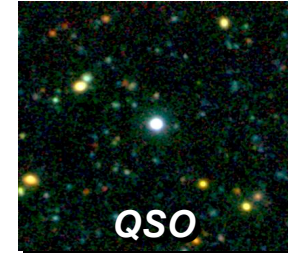
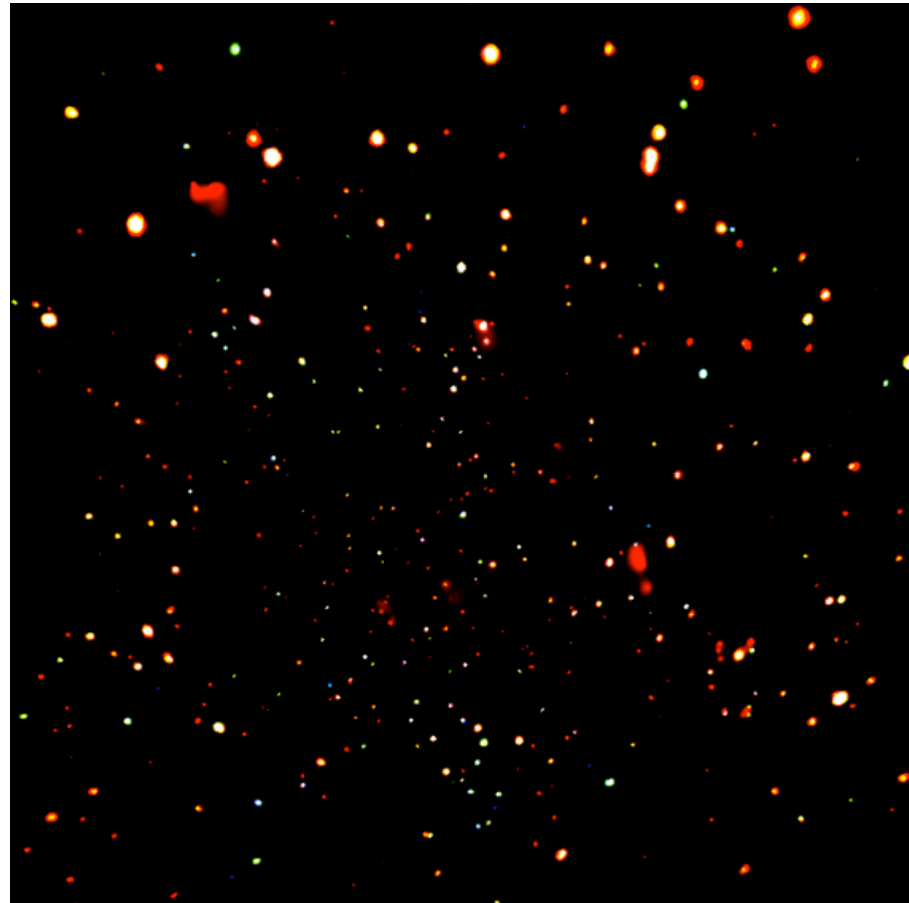
- 25-100 times gain in throughput over current missions
- Four soft X-ray (0.25-10 keV) telescopes and 12 hard X-ray (10-40 keV) telescopes, in a single spacecraft, at L2, pointing at the same target with the data combined on the ground

The Chandra Deep Fields

Chandra has resolved the X-ray background into active galactic nuclei (AGN) with a space density of a few thousand per sq deg

- ♣ Constellation-X will gather high-resolution X-ray spectra of the elusive optically faint X-ray sources
- ♣ Chandra deep surveys have the sensitivity to detect AGN up to $z \sim 8$

**2 Megasecond Observation
of the CDF-N**
(Alexander et al. 2003)

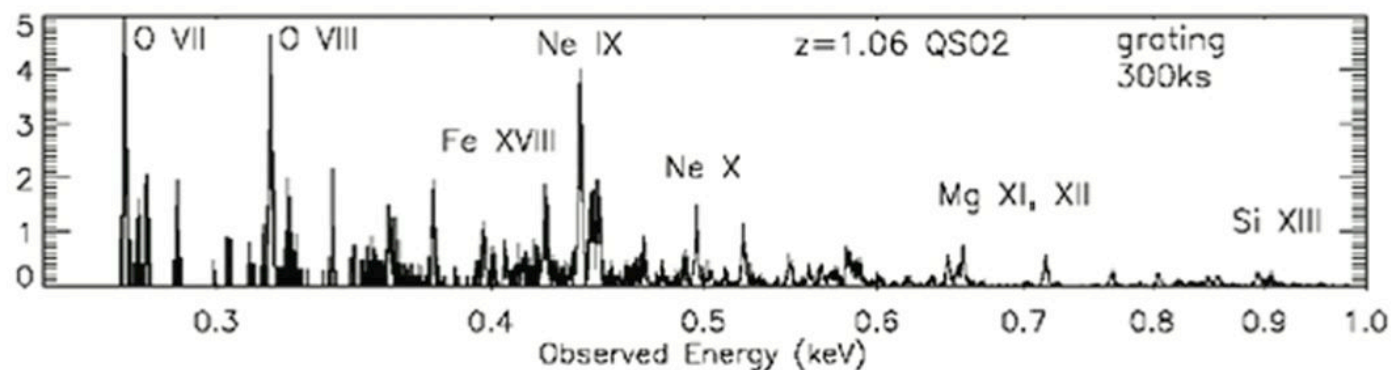


Chandra sources identified with mix of active galaxies and normal galaxies, many are optically faint and unidentified

Black Holes and the Cosmic X-ray Background

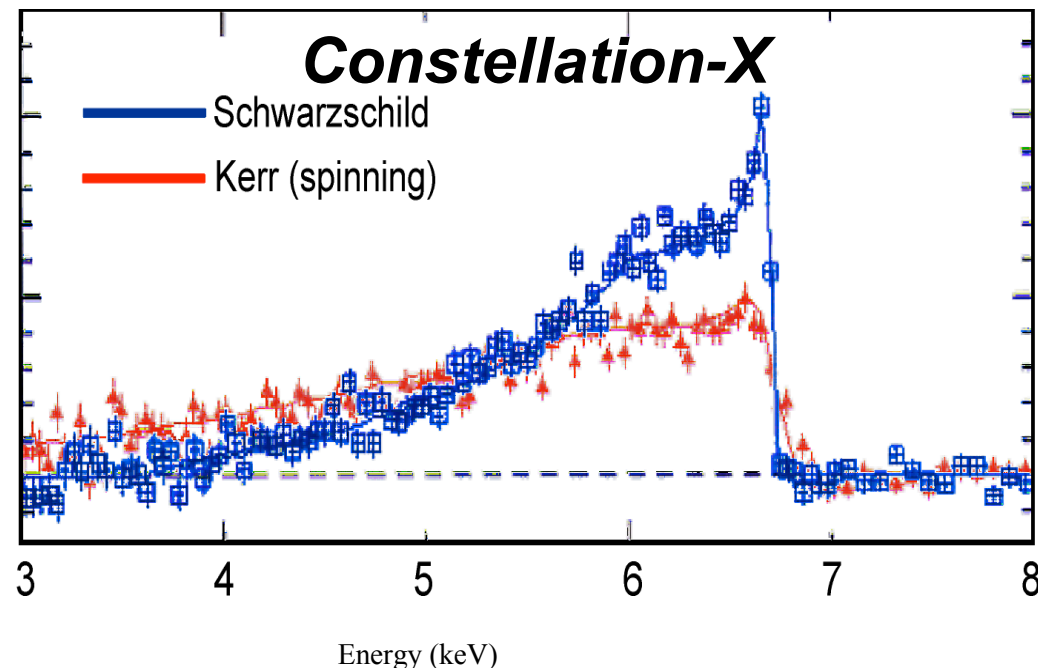
- ♣ Constellation-X will provide detailed spectroscopic IDs

Con-X simulation of faint $z=1.06$ “Type II QSO”



- ♣ Near the background peak energy (20-50 keV) only 3% is resolved (Krivonos et al. 2005)
- ♣ Constellation-X will have unprecedented imaging capability at 10-40 keV will resolve a significant fraction of the hard X-ray background

Constellation-X, Black Holes and Strong Gravity

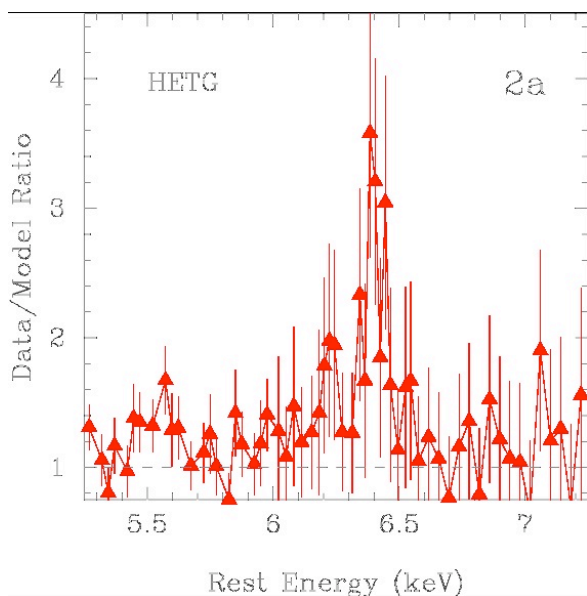


Time resolved X-ray spectroscopy near the last stable orbit:

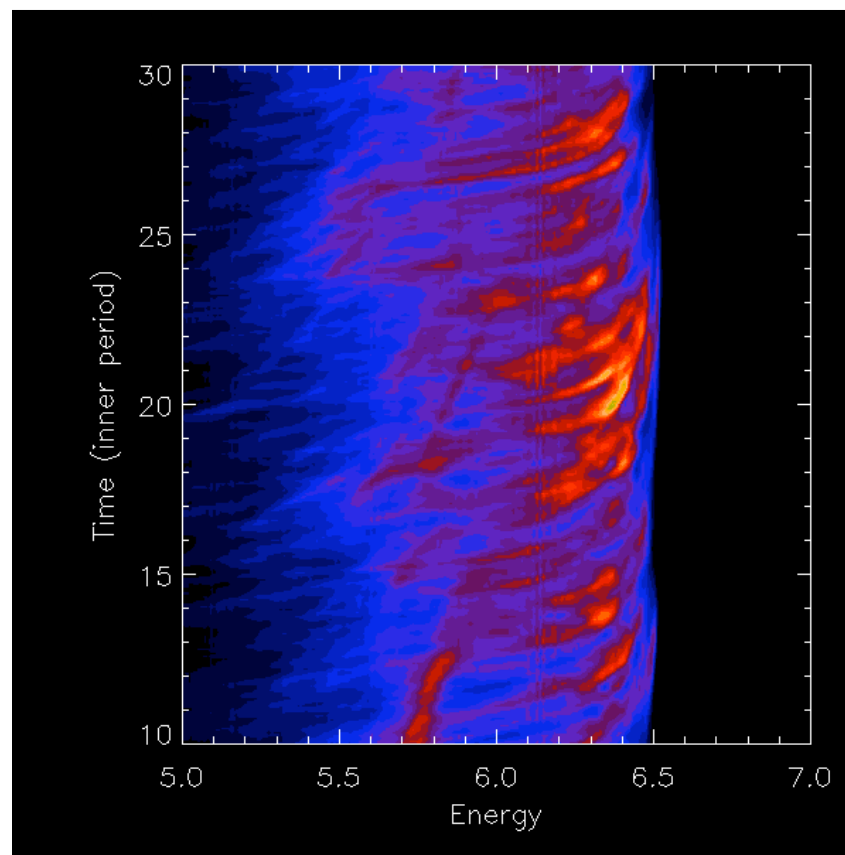
- } iron profile from the vicinity of the event horizon where strong gravity effects of General Relativity can be observed
- } Use Line profile to determine black hole spin
- } Reverberation analysis to determine black hole mass
- } Investigate evolution of black hole properties (spin and mass) over a wide range of luminosity and redshift

Iron Line Variability

- ♣ Constellation-X will allow detailed study of line variability
- ♣ See effects of non-axisymmetric structure orbiting in disk
 - | Follow dynamics of individual “blobs” in disk
 - | Quantitative test of orbital dynamics in strong gravity regime



Chandra-HETG data on NGC3516
(Turner et al. 2002)



Armitage & Reynolds (2003)

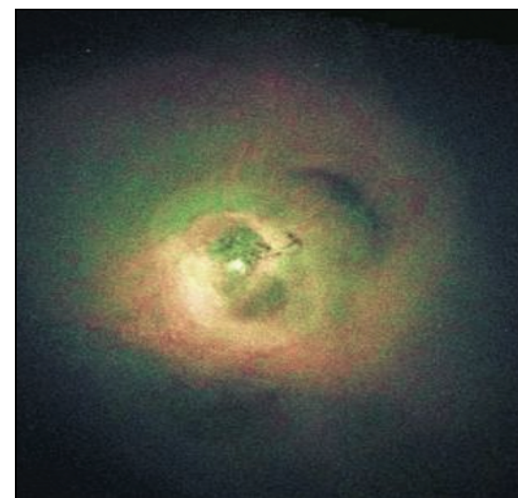
Evidence for non-axisymmetric structure may already have been seen by Chandra and XMM-Newton... Constellation-X area needed to confirm and utilize as GR probes

Black Holes and Cosmic Feedback

Large scale-structure simulations require AGN feedback to regulate the growth of massive galaxies (e.g., Di Matteo et al. 2005, Croton et al. 2005)

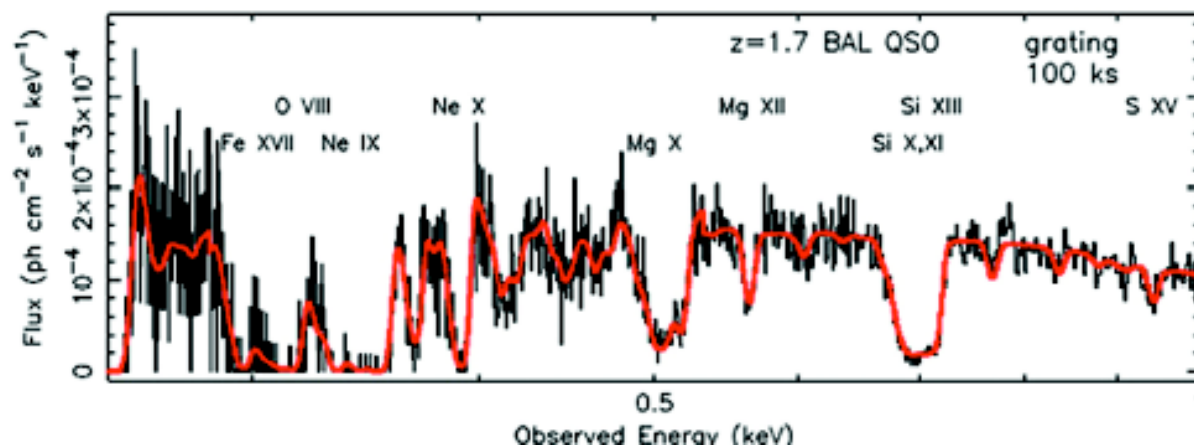
- ♣ Con-X's non-dispersive X-ray spectroscopy required to probe hot plasma in cluster cores (Begelman et al. 2003, 2005)

*Perseus Cluster of Galaxies
(Chandra image)*



- ♣ Con-X will reach the powerful AGN outflows in the quasar epoch ($1 < z < 4$)

Con-X simulation of BAL QSO (S.Gallagher, UCLA)



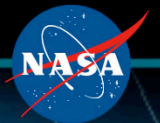
BEYOND EINSTEIN: From the Big Bang to Black Holes

Constellation

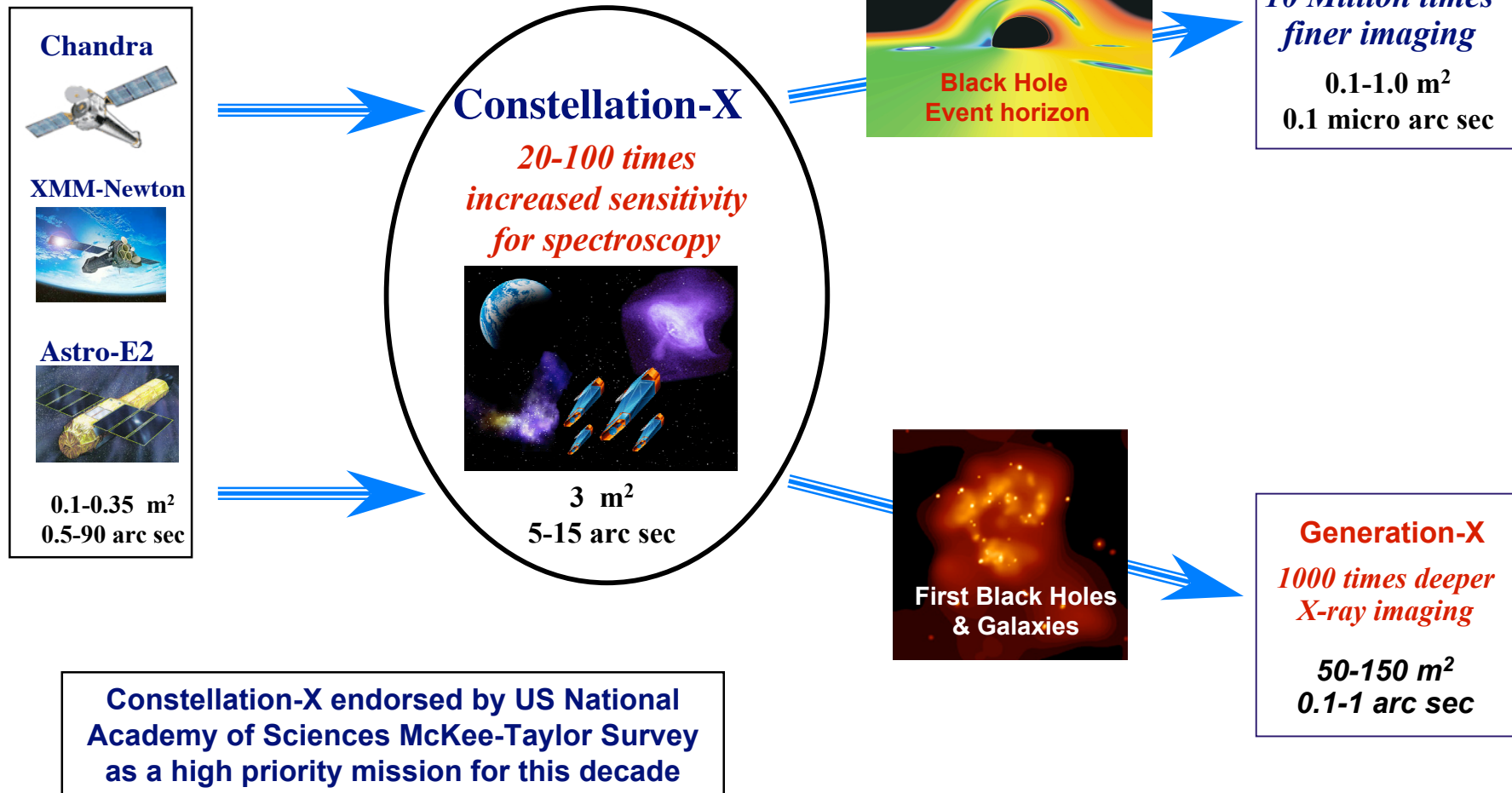
The Constellation X-Ray Mission

►► Enabling the Future

**What can be done with the current
Great Observatories?**



X-ray Astronomy Roadmap



Project #1:

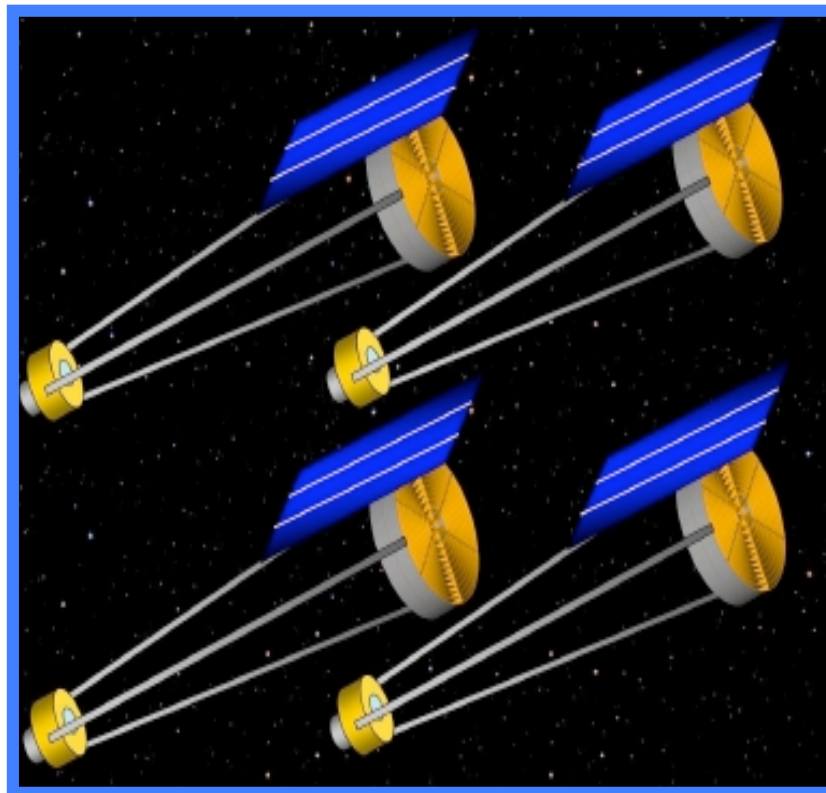
Pinpointing the X-ray Confusion Limit with an Ultradeep Chandra Survey

Advertisement: X-ray Surveys meeting November 5-7, 2006, Cambridge, MA

X-ray Astronomy in 2025/2030: The next time we'll have sub-arcsecond X-ray imaging capability??

- ♣ Gen-X is a NASA "Vision" Mission:
2-year study just completed
- ♣ Will have 0.1" optics and
100 m² collecting area
- ♣ detailed AGN studies to $z=10$,
X-ray evolution of star-forming
galaxies directly to $z=4$
- ♣ NOTE: ESA will fly XEUS around
2020 (?) with 2" angular resolution

Generation-X



Galaxies become
dominant below
 $1 \times 10^{-17} \text{ erg cm}^{-2} \text{ s}^{-1}$
(0.5 – 2 keV)

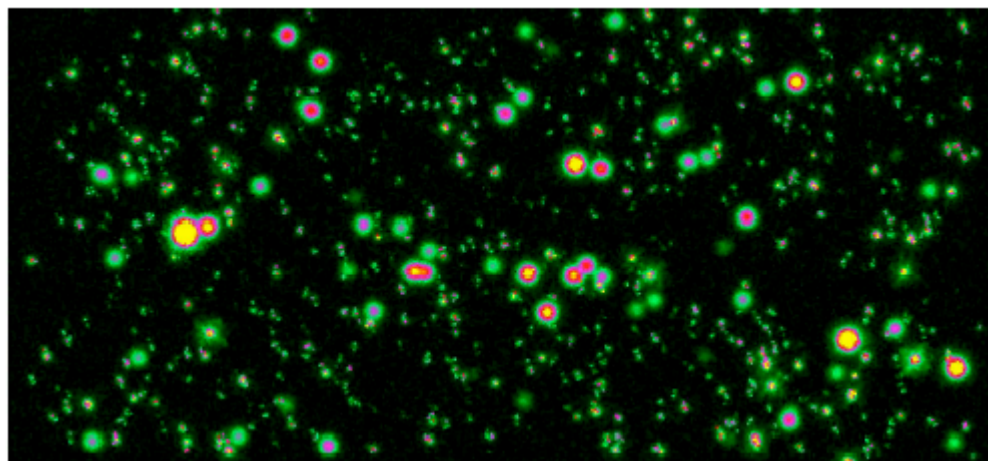
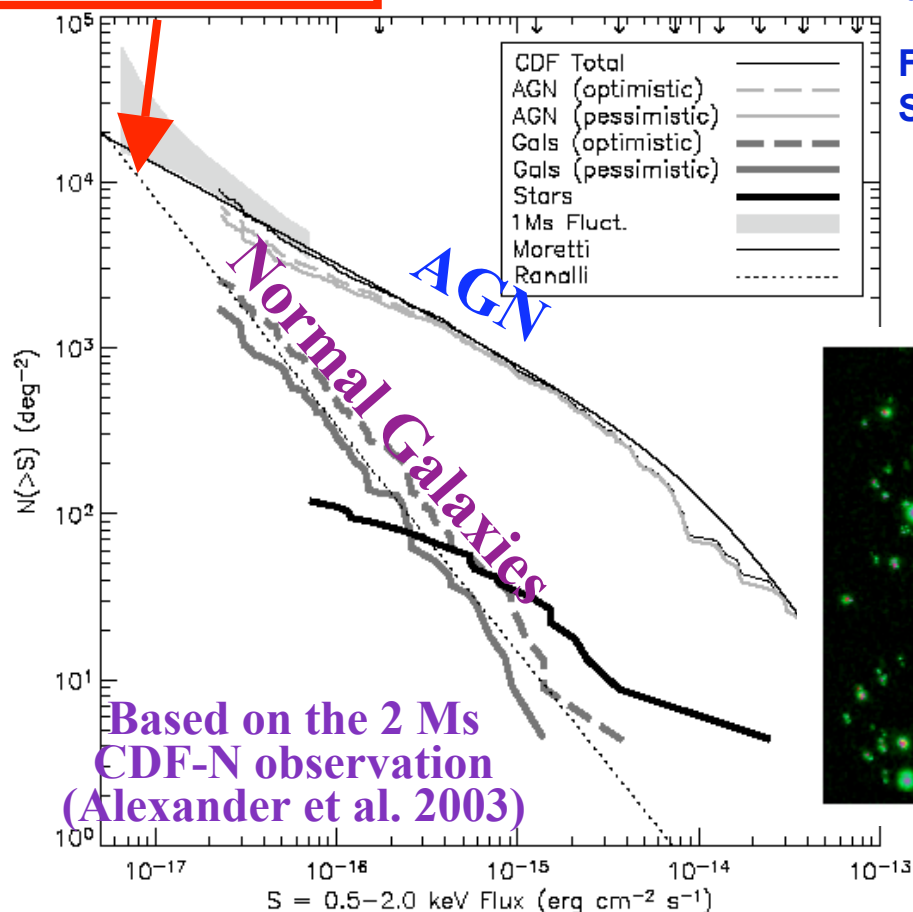
counts will have an “upturn” below
 $1 \times 10^{-17} \text{ cm}^{-2} \text{ s}^{-1}$ due to normal/star-forming galaxies

et al. (2004)

**CRITICAL: ULTRA-DEEP CHANDRA SURVEY
OF THE DISTANT UNIVERSE (5-10 Ms) to reach
below $1 \times 10^{-17} \text{ erg cm}^{-2} \text{ s}^{-1}$**

**Focus on deep survey fields with good
Spitzer + HST coverage for host galaxy ID**

Hubble Deep Field-North,
Gen-X 1 Ms simulation



Project #2:

Enhancing future dark energy cluster surveys with a large Chandra cluster survey program

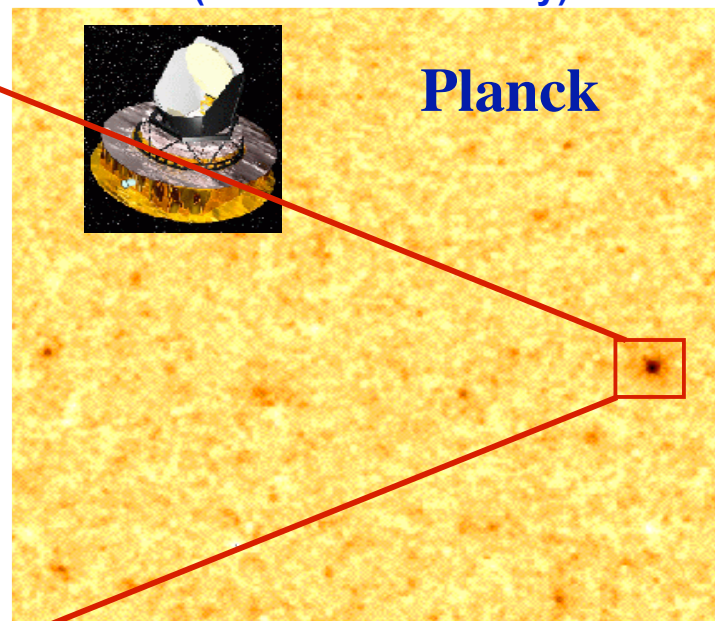
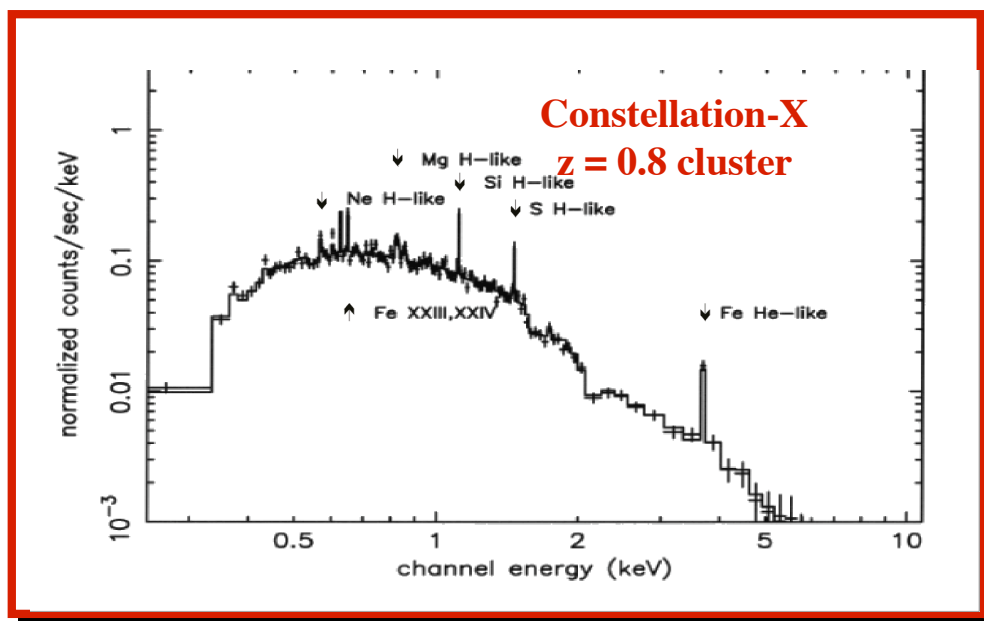
note: Con-X field of view is 2.5' x 2.5'

Cosmology with Clusters of Galaxies

Con-X will measure mass and temperature profiles (+ dynamics!) in clusters to high precision using spectroscopy

Issue: must have a large sample (hundreds) of $0.3 < z < \sim 1.0$ massive clusters of galaxies for Con-X

Suggest we ALSO continue to follow up the lower- z known X-ray selected clusters with Chandra GO program over the next 5+ years (Chandra FOV is key)



Planck

A Chandra imaging “pre-survey” would reduce the cost and risk of Constellation-X dark matter/dark energy studies

SZE derived cosmological parameters using 500 clusters Molnar et al (2002)

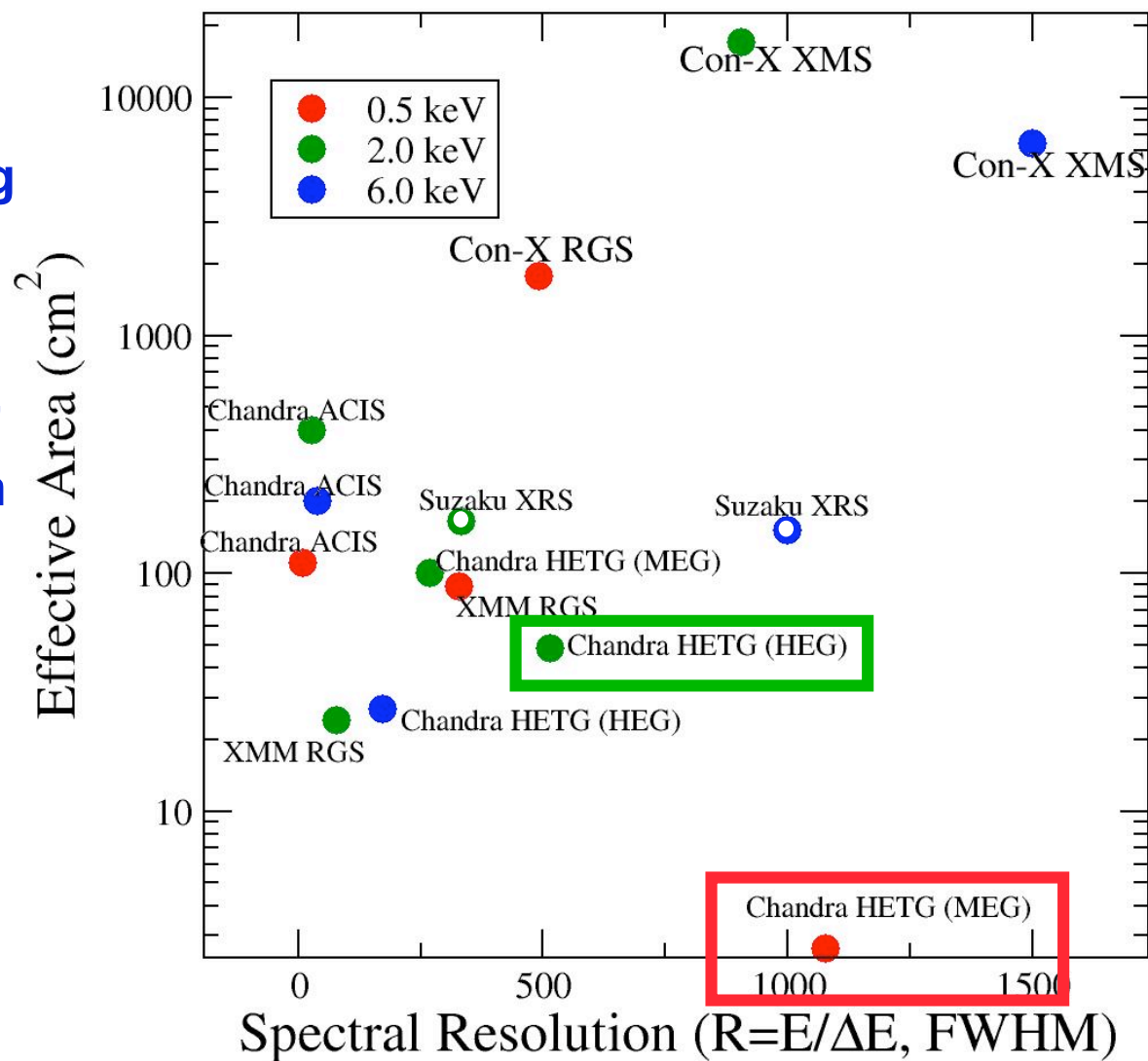
Project #3:

Pathfinder atomic
astrophysics with 500+ ks
Chandra HETG
observations

Current X-ray Spectrometers vs Con-X

- Chandra HETG has much smaller collecting area than Con-X

- particularly important in the 0.6-1.2 keV “Fe L” portion of the spectrum



Deep Chandra HETG Observations as Atomic Astrophysics Pathfinder for Constellation-X

Portion of the 300 ks Capella spectrum

- Example of faint lines:
Capella HETG spectrum
($\Delta\lambda \sim 0.014$ angstroms)

- Lyman series line ratios
useful for diagnosing
optical depths &
temperature

- Other topics include:
 - dielectronic
transitions
 - weak blending from
unidentified lines
(mostly Fe L)

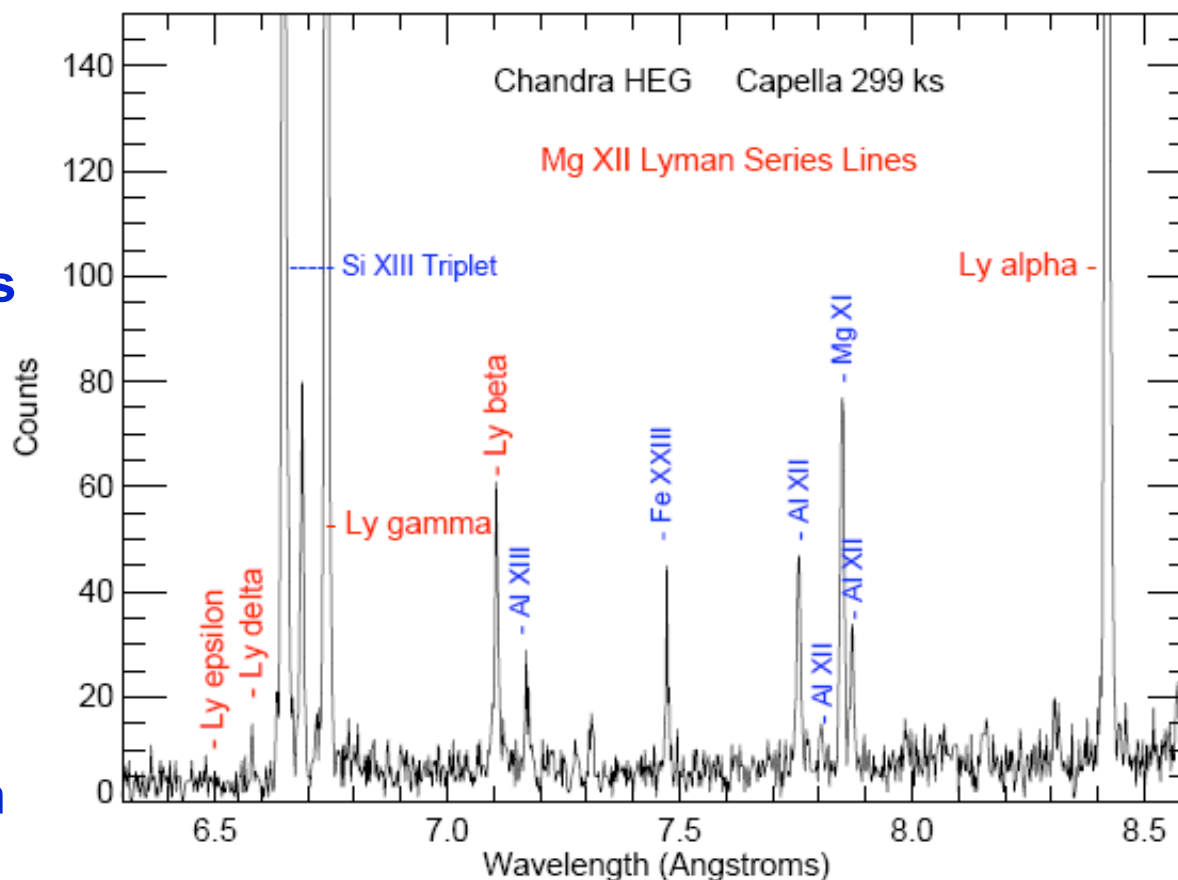


Figure courtesy of Nancy Brickhouse (SAO)

Mission Status:

- Launch date : 2018
- Mirrors fabricated at <15" angular resolution
- Flight-like calorimeters have achieved 3.2 eV spectral resolution (goal is 2 eV)
- Off-plane gratings show great promise for even better throughput and higher resolution
- Hard X-ray Telescope technology mostly at TRL6
- Basic single spacecraft design in hand

Project Scientist:

Nicholas White (GSFC)

Chair of the

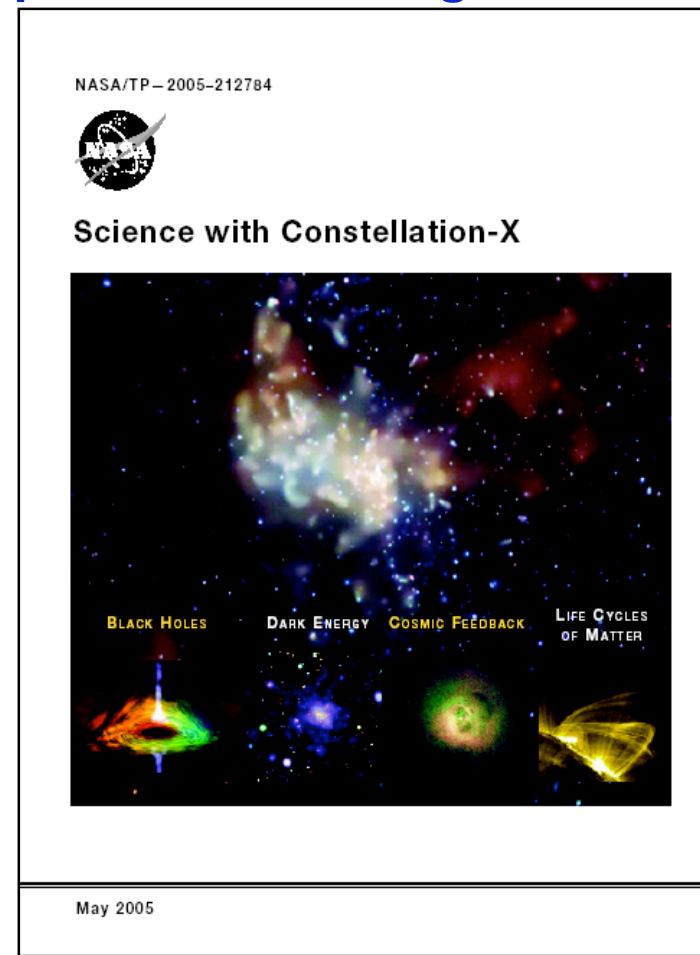
Facility Science Team:

Harvey Tananbaum (SAO)

Recent 40-page update to Constellation-X Science Case:

"Science with Constellation-X" booklet

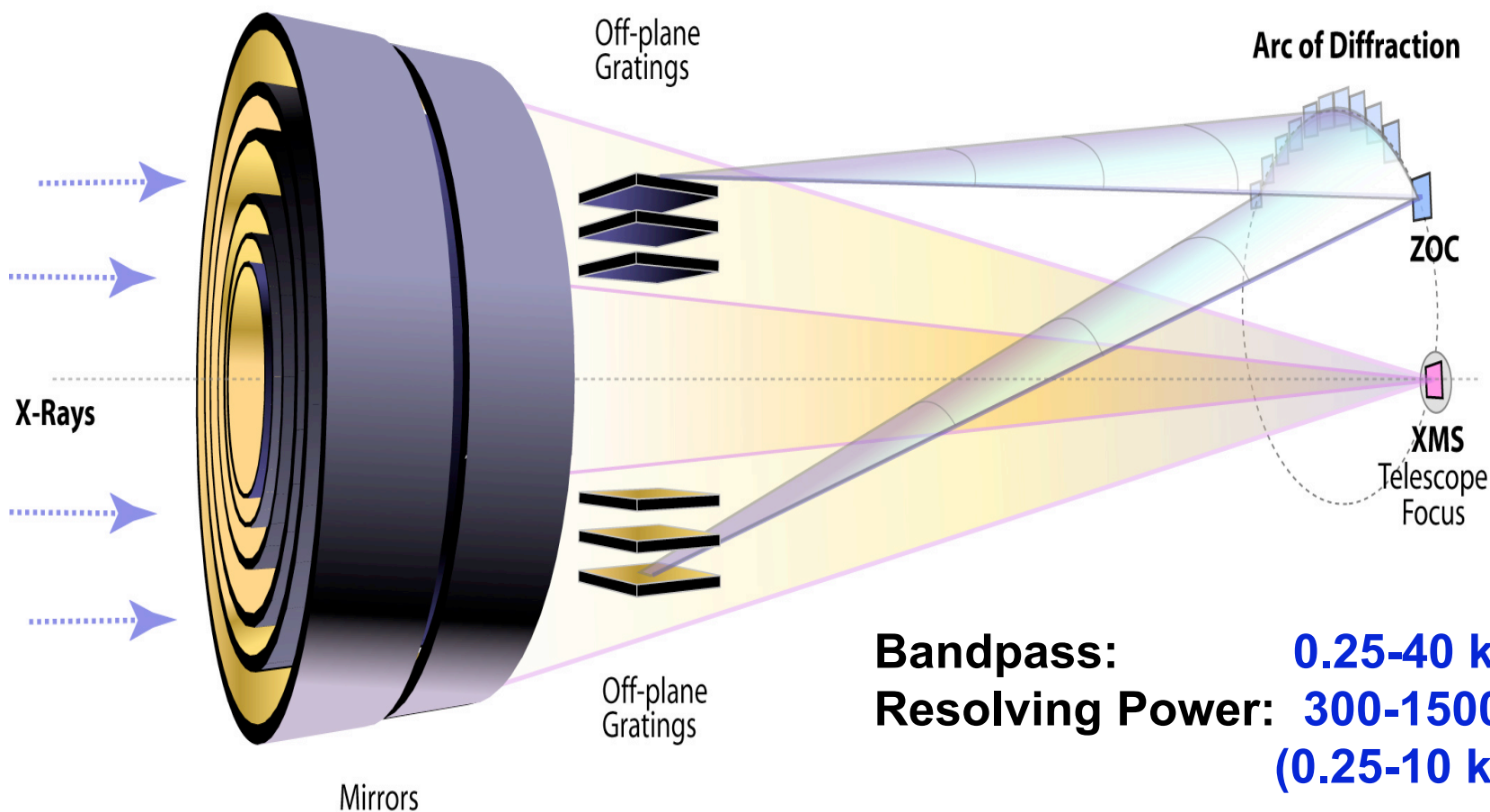
<http://constellation.gsfc.nasa.gov>



The heart of Constellation-X: A very large X-ray mirror

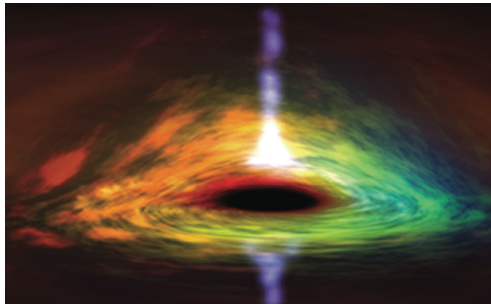
Areal density: 250 kg/m²

**Total collecting area: 1.5 m²
(@ 1.25 keV)**



Bandpass: 0.25-40 keV
**Resolving Power: 300-1500
(0.25-10 keV)**

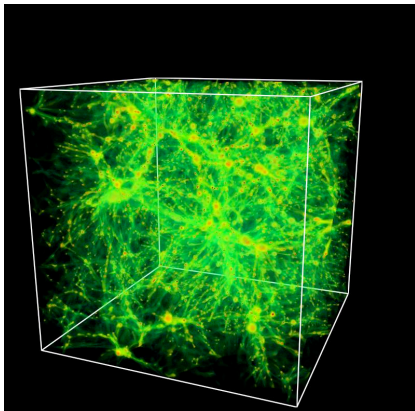
Constellation-X Science Objectives



Black Holes

Observe hot matter spiraling into **Black Holes** to test the effects of General Relativity

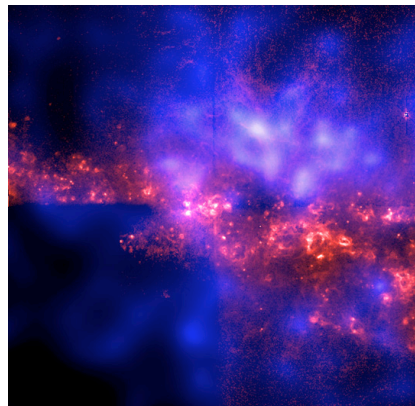
Trace their **evolution with cosmic time**, their contribution to the energy output of the Universe and their effect on galaxy formation



Dark Matter and Dark Energy

Use clusters of galaxies to trace the locations of **Dark Matter** and as independent probes to constrain the amount and evolution of **Dark Energy**

Search for the **missing baryonic matter** in the Cosmic Web

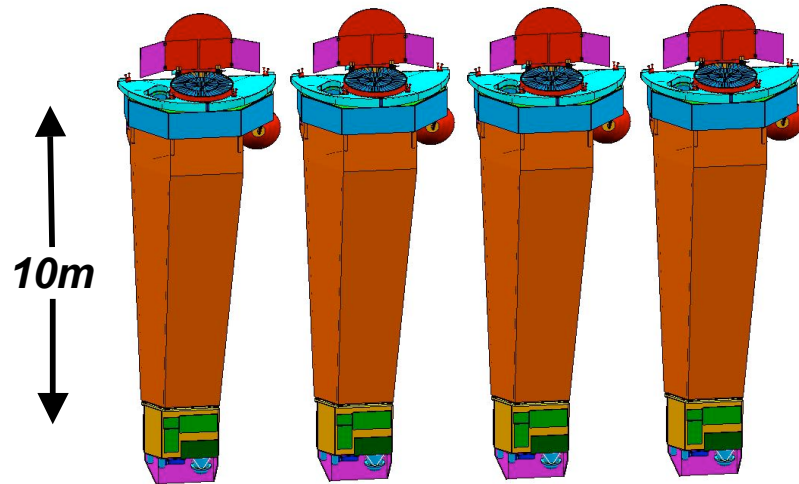


Cycles of Matter and Energy

Study dynamics of **Cosmic Feedback**

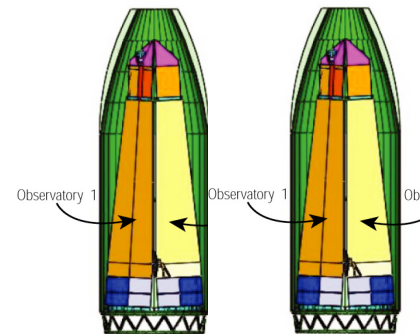
Creation of the elements in **supernovae**, The equation of state of **neutron stars**, **Stellar activity**, **proto-planetary systems** and X-rays from **solar system objects**

Mission Configuration Trade Study



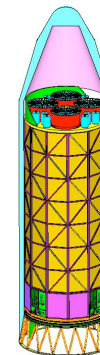
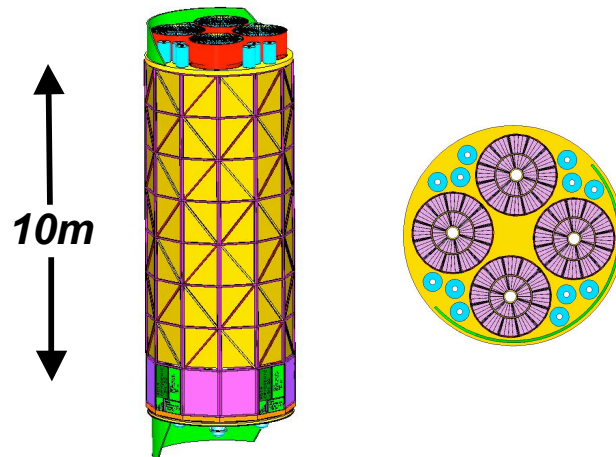
Past Reference Design

Launched in pairs on 2 Atlas V class launchers



Current Reference Design

Single launch on the new Delta IVH launcher

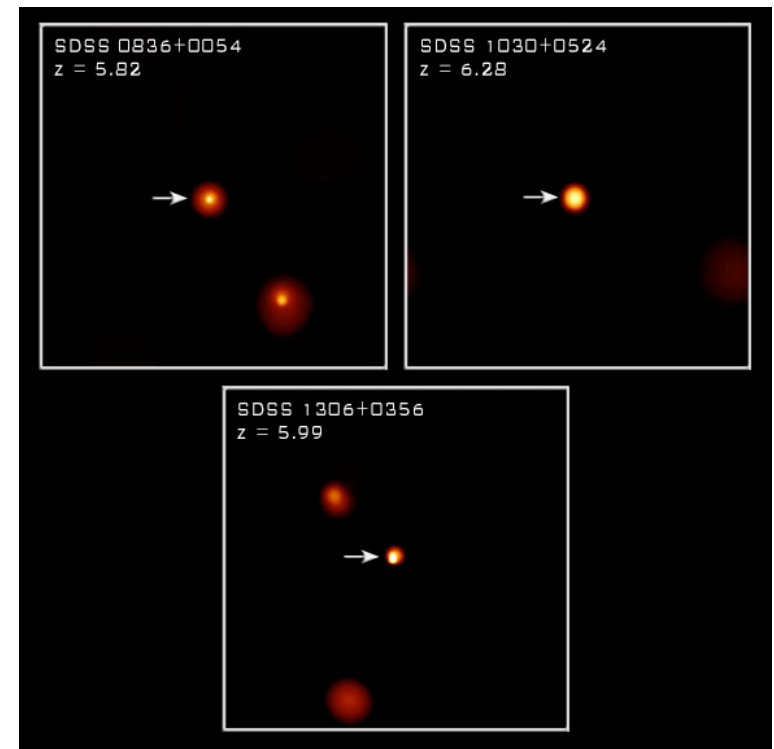


Launch cost saving of ~\$120M with no loss in science capability

X-ray Detections of High Redshift QSOs

Chandra has detected X-ray emission from three high redshift quasars at $z \sim 6$ found in the Sloan Digital Sky survey

Flux of $2-10 \times 10^{-15} \text{ erg cm}^{-2} \text{ s}^{-1}$ beyond grasp of XMM-Newton, Chandra or Astro-E2 high resolution spectrometers, but within the capabilities of Constellation-X to obtain high quality spectra



High resolution spectroscopy enables study of the evolution of black holes with redshift and probe the intergalactic medium of the early universe